

An Automatically Controlled Suction Device for Field Air Sampling*

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IN practically all industrial hygiene studies and investigations, air sampling of contaminants is a necessary part of the procedure. For a few of these contaminants, special devices have been designed and constructed with which it is possible to determine their concentration directly in the field. For others a measured quantity of air may be obtained by the use of evacuated flasks, aspirating bottles or gas pipettes.

For the great majority, however, the technic consists of passing air at a suitable rate of flow through one or more absorption bottles, tubes, or similar devices capable of trapping the contaminant. After this is done the sample is brought in to the laboratory for analysis.

The volume of air to be thus sampled depends upon the sensitivity of the chemical method and the accuracy desired. Usually, the larger the sample taken, the more accuracy is possible in the chemical determination.

In regard to the chemical determination, we have the advantage of a variety of methods, the accuracy and sensitivity of which are usually well known and controlled. But it is well to remember that just because the chemical determination of the contaminant is accurate, it does not neces-

sarily follow that the final result, that of the concentration of the contaminant in air, is equally accurate. This is due to the fact that the overall accuracy also depends upon the accuracy with which the air volume has been measured.

The measuring of the air volume, under field conditions, presents numerous difficulties which often result in errors far exceeding those associated with the chemical procedures. Furthermore, these errors are largely unpredictable because they are introduced as a result of various limitations in the measuring devices or conditions associated with the device used in aspirating the air.

The most common means used today for producing the necessary air flow through an absorber is some sort of a suction pump usually driven by an electric motor, but sometimes manually operated. The device used for measuring the air flow is either a vacuum gauge or, more often, the conventional Venturi type flow meter. While these instruments are capable of registering the air flow with good accuracy under controlled conditions, such as may be obtained in the laboratory, field conditions are often such that highly accurate information of the air volume sampled is difficult to obtain. This is due to the fact that these devices are not integrating the air flow over the entire period of sampling, but are only indicating the rate of the air flow at any given moment. Consequently if an ac-

* Presented before the Industrial Hygiene Section of the American Public Health Association at the Seventy-second Annual Meeting in New York, N. Y., October 14, 1943.

curate estimate of the air volume is to be obtained it is imperative that the air flow remain constant. It is this requirement which is the most difficult to achieve, and the failure to maintain uniformity is, I believe, responsible for most of the errors associated with air flow.

When using motor operated pumps repeated line voltage variations cause corresponding variations in the motor speed and consequent changes in the rate of air flow. These variations become especially serious at low rates of flow if it is obtained by controlling the motor speed with a rheostat and thus causing the motor to run below rated voltage. Particularly is this true with respect to small fractional H.P. motors of the universal type which are desirable to use for reasons of versatility. Some improvement may be had by using a constant voltage controlled motor in combination with a bleeder valve in the suction line. However, our experience has been that this will not satisfactorily control the air flow, especially at low rates of flow. That is because constant voltage does not necessarily result in constant speed, it being achieved only when the electrical and frictional resistances have become constant.

Other disadvantages associated with the liquid flow meters mentioned are:

1. Accidental loss of liquid in transportation
2. Loss of liquid due to surges produced by stepping on the suction hose or accidental breaking of its connections
3. Condensation of water in extremely cold weather, causing water to enter the u-tube or condense on the orifice
4. Difficulties in changing orifices when widely different ranges of air flow are desired

Consequently, if highest accuracy is to be obtained it requires two persons to obtain a sample; one to operate the suction device and one to pay attention to the collection of the sample.

In order to overcome the above difficulties, all of which are detrimental to an efficient and accurate sampling technic, our office undertook to develop an improved type of instrument which in its final form proved to be satisfactory.

In planning this instrument, certain minimum specifications were set up which it had to meet to be considered successful.

1. Air flow should be automatically, or at least semi-automatically, controlled.
2. It should be simple in construction and at the same time rugged, and easy to operate.
3. It should be applicable to both low and high sampling rates with equal accuracy; that is, in the range from 0.5 liter per minute to 28.3 liters (1 cu. ft.) per minute.
4. Parts should be easily accessible in the case for cleaning and repair.
5. It should be light in weight for maximum portability.

Theoretically the problem looked relatively easy. Several schemes were tried with regard to controlling the air flow automatically, and instruments were built and tested. While they met the specifications with regard to flow control, they did not satisfy the above specifications in one or more respects. Not until an entirely new type of flow meter had been devised, was a satisfactory solution achieved.

Inasmuch as this flow meter is very easy to construct and has proved exceedingly accurate and useful in connection with hand operated suction devices, it will be described in detail.

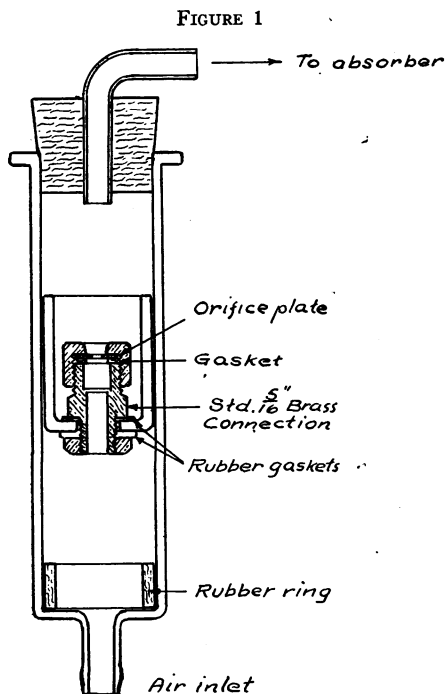
Basically the flow meter consists of a vertical cylinder in which a piston is allowed to move freely. The piston is provided with an orifice the size of which depends upon the rate of flow desired. When suction is applied above the piston, air will flow through the orifice. At a certain vacuum the pressure on the underside of the piston will be great enough to lift it and make it travel up in the cylinder. When the piston is floating steadily at any one

point, the air passes through the orifice at exactly the desired rate. A slight excess in the rate will make the piston rise, a slight reduction will make it fall.

In practice it is rarely possible to operate a suction device so uniformly that the piston will remain stationary for any length of time nor is that desired. It should be operated in such a manner that the piston is slowly rising and falling. *It is to be noted that the volume of air passing through the orifice in excess of the rated volume while the piston is rising a certain distance is exactly equal to the amount of reduction in air volume passing through while the piston is falling the same distance.*

Thus the average rate of flow will be exactly equal to that obtained if the piston were kept stationary.

Construction of the flow meter—A flow meter of the type shown in Figure 1 may be constructed from a 50 ml. hypodermic syringe. One discarded due to a broken tip will do as well as a new one.



The plunger should move easily in the barrel. Test it, after first inserting a rubber ring in the bottom of the barrel for protection, by holding it in a vertical position and letting the plunger drop of its own weight. It should travel smoothly and evenly to the bottom. Repeat the test a number of times, each time turning the plunger a fraction of a turn. If in any position the plunger should jam or slow up, indicating a tight fit, the barrel and plunger should be reground until satisfactory performance is obtained. This is easily done by making a thin slurry of fine carborundum powder in water, drawing a small amount of it into the syringe and working the piston back and forth with a rotary motion, turning the plunger now and then a fraction of a turn.

After having obtained the desired fit, have a glass blower replace the fine bore tip of the syringe with a 1" piece of glass tubing, 6 mm. inside diameter, to serve as air inlet. Cut off the plunger 1½" from the lower end and grind the edge flat. This piece will serve as the piston of the flow meter. Drill a ⅜" hole in the center of the bottom of the piston to take a standard 5/16" brass connection as indicated in the drawing. The brass connection is provided with an orifice plate made of sheet brass or lead and screwed tight by means of a cap against the seat which is covered with a gasket. The cap should be center-drilled with a 3/16" drill. The size of the orifice is determined by the trial and error method.

It is of course possible to cement a suitable size orifice directly over the bottom hole of the piston and obtain desirable results. However, the use of the brass connection not only provides a simple means of exchanging orifices but also provides added weight to the piston. A heavy piston will be relatively less influenced by frictional resistance in its up and down move-

TABLE 1

Calibration Data

| <i>Test No.</i> | <i>Liters Passed</i> | <i>Time in Seconds</i> | <i>Rate of Flow lit./min.</i> | <i>Deviation from Average Per cent</i> |
|-----------------|----------------------|------------------------|-------------------------------|--|
| 1 | 7.1 | 903 | 0.472 | -0.21 |
| 2 | 7.1 | 901 | 0.473 | ±0.00 |
| 3 | 7.1 | 902 | 0.472 | -0.21 |
| 4 | 7.1 | 899 | 0.474 | +0.21 |
| 5 | 7.1 | 899 | 0.474 | +0.21 |
| 6 | 7.1 | 901 | 0.473 | ±0.00 |

Average rate of flow = 0.473 lit./min.

Max. deviation from average = 0.21%

ments. A total weight of 45 to 50 gm. has proved to be the most satisfactory.

A piston may also be made from brass, as has been done in the instrument later to be described.

A flow meter constructed according to the above description was provided with an orifice to give a rate of flow of approximately 0.5 liters per minute. In calibration tests it was connected to an absorber and air drawn through by means of a midget impinger pump (which had been slightly altered to serve the purpose) and operated in prescribed manner. The air volume was measured by means of a wet meter.

As shown in Table 1 calibrations gave an average rate of flow of 0.473 liters per minute with a maximum deviation from the average of 0.21 per cent.

Automatically controlled air flow—

The idea suggested itself that this device could be modified to control the air flow automatically. The simplest possible means for accomplishing this would be to let the piston itself cut off the air stream when the desired rate of flow is exceeded. Such an arrangement is shown in Figure 2. It is similar in principle to that used in the M.S.A. midget impinger.

In practice, this device would be operated so that the rubber pad attached on top of the piston would press against the air outlet.

Two different locations of this flow

meter are possible; (1) in front of the absorbers, and (2) at the outlet of the suction device. In the former case, suction is applied to the outlet of the flow meter; in the second case, pressure is exerted at the inlet.

Table 2 shows calibration data for both locations under various conditions. The air flow was produced by means of a motor driven rotary pump. Inasmuch as it was desired to obtain figures which would reflect the maximum variations which it might be possible to obtain in the field by various operators, the suction pump was operated at arbitrarily chosen speeds without any attempts to obtain any check results. Study of Table 2 shows that while this control device after proper refinement might possibly be used if connected in front of the absorber, it is unsuitable if used on the outlet side of the pump.

For practical reasons, however, it is highly desirable to use the flow meter on the outlet side of the pump. Con-

FIGURE 2

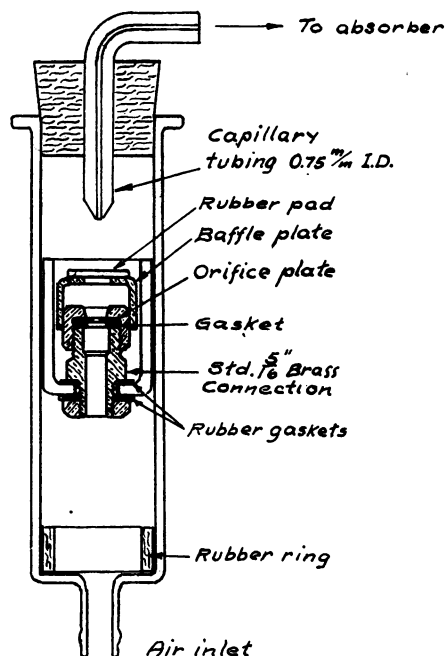


FIGURE 3

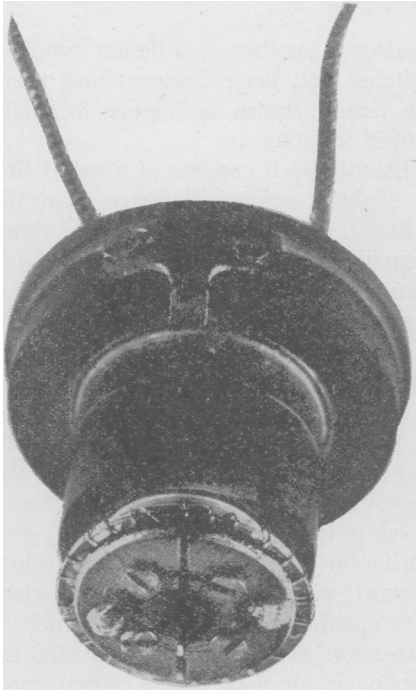
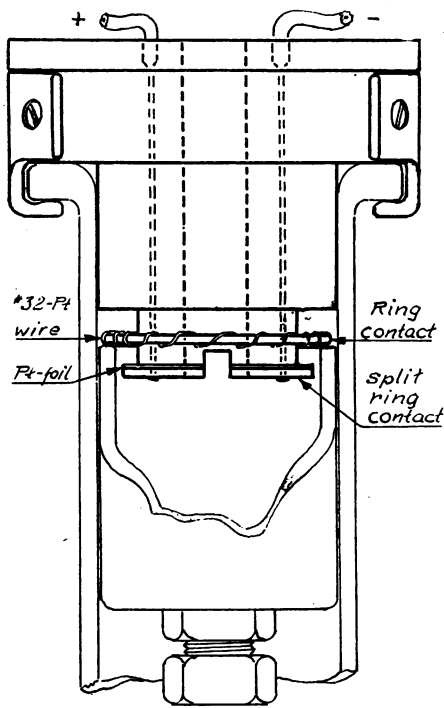


TABLE 2
Calibration Data

| Suction | | | |
|------------------------------------|--------------------------------------|-------------------------------|---|
| <i>Test No.</i> | <i>Operation of Suction Pump</i> | <i>Rate of Flow lit./min.</i> | <i>Deviation from Average in Per cent</i> |
| 1 | Slow—Just enough to raise the piston | 0.479 | —0.8 |
| 2 | Increased speed | 0.498 | +3.1 |
| 3 | High speed | 0.492 | +2.3 |
| 4 | Air hose collapsed | | |
| | Same as No. 1 | 0.462 | —4.3 |
| Average rate of flow = 0.483 | | | |
| Max. deviation from average = 4.3% | | | |
| Pressure | | | |
| 1 | Low speed | 0.535 | ± 0.0 |
| 2 | High speed | 0.774 | +44.7 |

sequently, some other means of controlling the air flow had to be found.

As shown in Table 1 the most accurate air flow is obtained when the plunger is slowly rising and falling. It was felt that this mode of action should be maintained and be utilized for controlling the air flow.

The use of a photoelectric device, where the piston would interrupt a beam of light when rising to a certain point, was considered as a possibility for controlling the motor driving the pump. However, this was considered too delicate and complicated to incorporate in a field instrument and was abandoned in favor of a directly actuated switch. In order to obtain maximum reliability such a switch should fulfil the following requirements:

1. Have the capacity to carry the total operating current.
2. Produce instantaneous response when actuated.
3. Require minimum power for its operation; that is, not materially resist the movement of the piston.

4. Electrical contacts should resist corrosion and pitting.

After a number of different types of switches had been designed and tried, the design shown in Figure 3 finally proved satisfactory.

Essentially it consists of a metal ring of slightly smaller diameter than the cylinder, and free to move up and down a small distance. Normally this ring is resting on the two halves of a split metal ring permanently fastened to the lower end of a cylindrical plug made from plastics. The diameter of this split ring is slightly less than the inside diameter of the piston. Each half of the split ring is electrically connected to the opposite terminals of a fixed resistance which in turn is connected in series with the motor. The piston when traveling upward will eventually lift the ring, thus opening the short circuit which in turn slows down the motor, causing reduction in air flow. As a consequence, the piston will travel down until the metal ring again makes contact with the split ring and thus short circuits the re-

sistance and speed up the motor. To insure good electrical contact, the ring contact is wound with platinum wire and the contact surface of the split ring halves covered with platinum foil. A suitable condenser is connected across the terminals of the latter to minimize arcing.

The plug may be turned from any convenient plastics. It should be provided with means of holding it securely in place in the top of the cylinder. A hole $\frac{3}{8}$ " in diameter bored through the center serves as an outlet for the air.

Inasmuch as very small fluctuations are accomplished by the plunger when in operation, it is best to provide a tripod on which the plunger rests when not operating. This may be easily constructed by soldering three stiff wires to the inside wall of a 1" long brass tubing of slightly smaller diameter than the inside diameter of the barrel. The points on which the plunger rests should allow a clearance between the plunger and the ring contact of from $\frac{1}{4}$ " to $\frac{1}{2}$ ".

FIGURE 4

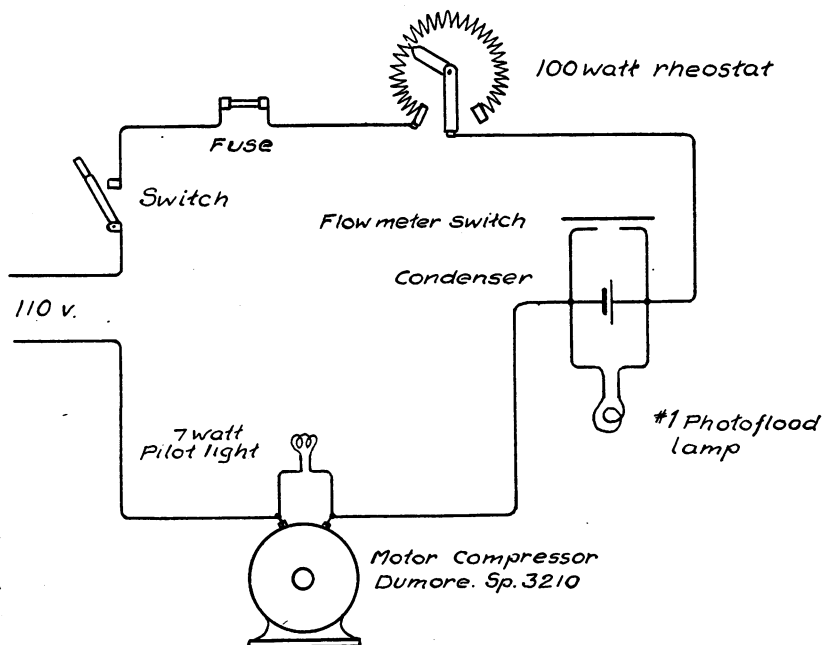


Figure 4 shows the wiring diagram of the assembly. For good operation the fixed resistance mentioned above should be so selected that approximately 10 volts variation occurs across the motor between the open and closed position of the switch at full load. With the type of motor compressor shown, this is achieved with a No. 1 Photoflood lamp. Incidentally this lamp may be used as a visual indicator of how the device is working. In the model shown, a pilot light visible through the panel also serves the same purpose. This light is connected across the terminals of the motor. It enables the operator to see at a glance even from a considerable distance whether the collection device is working properly or needs adjustment. A fast flicker of the light indicates proper operation. If the light is steady the speed is either too slow or too fast.

No lubricant is used or needed. As a matter of fact, if lubricant is applied the piston will stick, which prevents the device from functioning. For this reason a trap, preferably filled with copper wool, should be connected in the line between the pump and the flow meter to prevent the accidental entry of oil into the cylinder.

Hinged panels on the case are provided to permit easy access for inspection, cleaning, and repair.

A trap is located on the inlet side of the pump identical in construction to that on the outlet side. These traps not only serve as protection for the pump and the flow meter but also act as mufflers against the otherwise noisy operation of this type of pump.

Table 3 shows calibration data obtained with this instrument. An effort was made to simulate the various ways the instrument might be operated by different operators. Thus the maximum deviation of 0.95 per cent shown in the table should represent the highest error to be expected at any time. While this in itself is an extremely good performance, even better results may be obtained if each individual operator calibrates the air flow, running the instrument in the same manner as he would do it in the field. Personally, being familiar with the instrument, I have no difficulty in obtaining any number of calibrations showing less than 0.5 per cent variations.

Theoretically there should be no difference in the rate of flow when absorbers of different resistances are used on the suction side. In the previously shown calibrations one absorber was used in the tests because with this type of absorber we have as yet

TABLE 3
Calibration Data of Automatically Controlled Suction Device
(one absorber used)

| <i>Test Run No.</i> | <i>Manner of Operation</i> | <i>Volume of Air Passed Through Flow Meter</i> | <i>Time of Run</i> | <i>Rate of Flow lit./min.</i> | <i>Deviation from Average in Per cent</i> |
|---------------------|---|--|--------------------|-------------------------------|---|
| 1 | Lowest practical speed—Lamp resistance barely glowing | 56.8 lit. | 27'03" | 2.10 | —0.95 |
| 2 | Low speed — Lamp resistance glowing faintly | " | 26'58" | 2.11 | —0.47 |
| 3 | Higher speed—Lamp resistance glowing strongly | " | 26'44" | 2.12 | ±0.00 |
| 4 | Highest practical speed—Lamp resistance glowing very strongly | " | 26'27" | 2.14 | +0.95 |
| 5 | Motor started cold the following day — Operated like Sample No. 2 | " | 26'45" | 2.12 | ±0.00 |

Average rate of flow = 2.12 lit./min.

Maximum deviation from average = ±0.95%

found no need for greater numbers when sampling. However, recognizing the possibility that such occasion might occur the experiment recorded in Table 4 was performed. Notice the high vacuum required for these absorbers at this rate of flow. The drop in rate of flow becomes progressively higher with each additional absorber.

TABLE 4

Comparison Between Rates of Flow When Using Different Numbers of Absorbers in Series

| <i>Number of Absorbers Used</i> | <i>Suction Required Inches of Mercury</i> | <i>Rate of Flow lit./min.</i> | <i>Variation of Flow in Per cent</i> |
|---|---|---------------------------------------|--|
| 1 | 2.5 | 2.12 | ± 0.0 |
| 2 | 5.0 | 2.08 | -1.9 |
| | | 2.08 | |
| | | 1.97 | |
| 3 | 7.5 | 1.99 | -6.6 |
| | | 1.98 | |

While this performance was not noticed when the instrument was new but showed up in this test after about 150 hours of operation, it must be taken into consideration if the pump has to work against very high resistance. It is caused by air leaking in through the bearings of the rotary pump. Consequently it is advisable, as is the case with all these devices, to make periodic

calibrations, and especially when unusually high vacuum is to be used for inducing the air flow.

The instrument just described and demonstrated has proved itself exceptionally trouble-free. This is probably due to two factors: the presence of the protective traps on each side of the pump and the reliability of the switch. The latter is, of course, the source from which most of the trouble would be expected. However, since the instrument was built and passed through the experimental stages, it has been in use approximately 150 hours, during which time the switch has opened and closed without a single failure for an estimated million and one-half times, a record which seems rather satisfactory.

While the instrument as described was designed to meet our own demands for portability and refinements, I see no reason why the control device could not be successfully adapted to some of the already existing suction devices. I suggest that you try it. If you succeed I shall feel happy to have contributed, in whatever small degree it may be, to the achievement of that other freedom we also so ardently desire, namely, freedom from trouble.